GROWING PEBBLES AND CONCEPTUAL PRISMS – UNDERSTANDING THE SOURCE OF STUDENT MISCONCEPTIONS ABOUT ROCK FORMATION

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ABSTRACT

Students hold a surprising number of misconceptions about how rocks form. This study analyzes narrative essays - stories of rock formation - written by pre-service elementary school teachers. Most students had completed a college-level course in earth science, yet expressed startling misconceptions, including pebbles that grow, human involvement in rock formation, and sedimentary rocks forming as puddles dry up. These misconceptions arise from deeply held but largely unexamined beliefs, called here conceptual prisms. Conceptual prisms result from the interaction of the student's world view and personal experiences. These beliefs are largely unaffected by traditional science instruction. Instead, students experience instruction refracted through their conceptual prisms, resulting in a spectrum of student ideas about geology. Instruction that does not explicitly address misconceptions and the underlying conceptual prisms is likely to be ineffective.

Keywords: Education - geoscience; geoscience - teaching and curriculum

INTRODUCTION

I recently asked students in an introductory college geology course to write stories describing how rocks form. This kind of narrative assessment makes student thinking visible, allowing recognition of student misconceptions and sources of students' confusion. I was astonished to find that many students believe pebbles grow. Describing how sedimentary rock forms, students told stories of sand clumping in the bottom of rivers to form pebbles. I was flabbergasted. In 15 years of teaching geology, it had never occurred to me that students believe that pebbles grow. That experience launched this study.

The goal of the study was to identify patterns in students' thinking about rocks. I was interested both in specific misconceptions about how rocks form and in the underlying thinking and beliefs that generate those misconceptions. Students wrote stories describing the formation of various kinds of rocks. These stories were analyzed to identify common misconceptions. The misconceptions were then analyzed for patterns to reveal underlying beliefs and thought patterns of students. The study addressed three basic research questions:

How do students describe the process of rock formation in narrative essays?

Are there common patterns in students' naive conceptions about geology?

Can these patterns be explained by a few underlying beliefs that shape student ideas?

MISCONCEPTIONS IN GEOSCIENCE

The identification of student misconceptions in science has a research tradition stretching back 20 years (Driver, Guesne and Tiberghien, 1985; Gilbert and Watts, 1983; Gunstone, White, and Fensham, 1988; Osborne and Freyberg, 1985). While extensive efforts have been made in physics, biology, and chemistry to identify student misconceptions, misconception research in the earth sciences has been more limited. Most research in geoscience misconceptions has focused on concepts in space science (Schoon, 1995; Sharp, 1999; Sneider and Ohadi, 1998; Vosniadou, 1992), water science (Bar, 1989), and atmospheric science (Boyes, Stanisstreet and Papantoniou, 1999), with less work done on geological concepts (Marques and Thompson, 1997; Stofflett, 1994).

Misconception research arises from a constructivist view of science learning (Driver, 1989; Gilbert, Osborne and Fensham, 1982). This view of knowledge posits that learning is a complex process in which instructional experiences interact with the learner's existing beliefs, experiences, and knowledge. Student learning always depends on what students bring to the classroom as well as the experiences they have there. If learners already have theories of how the world works, instruction must be structured to acknowledge and challenge those misconceptions (Osborne and Wittrock, 1985).

The study and its limitations - Student essays were analyzed to find patterns in student thinking. This study investigates the work of one class consisting of 24 students.

Let me be clear about what this study represents. It is an intensive investigation into student thinking in a small population. It is an analysis of student work in context, rather than an interview protocol designed to elicit student thinking in depth. This means that this study identifies the minimum frequency of ideas; more students may share those ideas but did not express them in these essays. While the methodology used is quantitative, I make no claim that the quantitative results are precise. They are simply general indicators of the pervasiveness of particular student ideas.

METHODOLOGY

Research Methods -The methodology of the study grows from two research traditions: grounded theory and content analysis. Grounded theory is an approach to educational research in which theory grows from observation (Straus, 1987). Grounded theory contrasts with quantitative research in education that typically tests a pre-specified hypothesis - e.g., one particular approach to teaching students to decode words is more effective than another. Grounded theory is analogous to field research in geology in which the geologist approaches a new field area armed with a theoretical underpinning - a plate tectonic model, perhaps. Specific hypotheses, however, grow out of observations of stratigraphy and geologic structure. The theoretical underpinnings of this study lie in constructivist and misconception research. Specific hypotheses about student misconceptions and the belief systems that underlie them were developed as the research proceeded.

Content analysis is a methodology in which text is analyzed for patterns (Rosengren, R.E., 1981). Student essays were read to identify recurring patterns. From these patterns I identified tentative categories for analysis. As the categories were identified each student paper was coded for those categories. This is a recursive process. As more categories were identified each student paper was reread to code that category. Once all the papers were coded, the results were quantified for analysis.

The Students -All of the students in this study plan to become elementary school teachers. Twenty of the twenty-four students (83%) had completed the other required geology course in their program, a lecture course in earth science. Thirteen (54%) had taken that course on our campus; seven (29%) took it at a community college. The remaining four students had an earth science course in high school. All college courses included instruction on rock formation; the content of the high school courses is unknown.

This group had a typical demographic for students enrolled in the pre-elementary school program. 92% are women, 62% Caucasian, 8% Hispanic, 21% Asian-American, 4% African-American, and 4% Pacific Islander. English is not the native language of 25% of the students. All of the class was within 4 semesters of graduation. Final course grades in this class averaged 2.7, slightly below the usual course average.

The course - The data was collected in an activity-based course, entitled "Rocks, Minerals and Fossils", designed for preservice elementary school teachers. Assessment includes three quizzes and weekly essays. Some of the data used in this study came from the weekly essays.

The Essays - The data for this study consists of four sets of student essays. The first essay was administered in class before any instruction on rocks occurred in this course, though almost all the students already had some instruction in rock formation in traditionally structured lecture or lecture-and-lab courses. The remaining three essays were homework assignments. Essays were collected and duplicated for analysis at the end of the semester. Details of the four essay tasks are presented in Table 1. While essays were collected from 24 students, not every student completed all four tasks due to class absences and failure to turn in homework assignments. A total of 87 essays were analyzed.

The Analysis - The analysis yielded thirteen coding categories, detailed in Table 2. Detailed data are provided in the discussion that follows, but three overarching patterns of student misconceptions are apparent. First, a variety of student misconceptions could be identified. As suspected, a substantial proportion of students cited growing pebbles or other accretionary model of rock formation. Some students believed that because a rock was found by a river, or because it was a rounded pebble, it must be a sedimentary rock. These misconceptions form an almost bewildering array when considered one-by-one.

Individual student thinking patterns were not necessarily consistent through time. A student who cited an accretionary model (e.g., sand gluing onto a pebble, or dirt clumping up in a puddle) in one essay often did not describe an accretionary model in a different essay. I wish I could attribute this to improved performance due to instruction. Unfortunately, students were just as likely to move from a scientifically accurate model to an accretionary model as they were to do the reverse. The overall picture is one of confusion, not of well-defined conceptual structures.

Finally, student misconceptions were loosely linked. Students who used the word "rock" as synonymous with "clast" were likely to tell accretionary stories, and were likely to believe that the source rock of a given sedimentary rock must be the same rock. This linkage is due to underlying belief systems that result in the misconceptions students express. I devoted the remainder of the analysis to identifying possible beliefs that could account for the misconceptions.

CONCEPTUAL PRISMS

To explain how student beliefs create loosely linked misconceptions, I created the construct of the conceptual prism (Figure 1). A conceptual prism is a deeply held but largely unexamined belief about the world. Prisms are generated as the individual's world view interacts with meaningful experiences to produce belief.

Pretest: administered on first day of rock unit, before instruction. The pretest included collection of data on previous geology instruction. Prompt: Suppose you are walking by the river and find a pebble made of sandstone. Write the story of that sandstone from the time its particles weathered from some source rock until the sandstone became a rock.
Pet Rock I: administered as homework following first day of rock unit. Students were given one page introduction to rocks (definition, 3 kinds). Students had completed rock scavenger hunt (finding rocks of different colors, shapes and textures on a river levee), pet rock observation, rock "classification" (choosing student-originated descriptors to sort rocks). Prompt: Write the history of your pet rock. How did it form and where? How did it get to where you found it? Don't worry if you don't feel like you know anything about rocks yet - this is supposed to be just a guess.
Graywacke story: administered as homework. Students had completed activities in weathering, independent inquiry into sand, "Sedimentary Rock Imagery", sedimentary rock identification, "Rocks Tell a Story" (group interpretation of interesting large samples), and table-top mapping of sedimentary environments. Prompt: Write the story of graywacke from the time its particles weathered from some source rock until the graywacke is a rock. You can use "Sedimentary Rock Imagery" as a guide, but include as much good geology as you can. Include your hypothesis as to what kind of igneous rock weathered to make the particles in graywacke. DO NOT LOOK THIS UP IN A BOOK.
Pet Rock II: administered as homework at close of rock unit. Students identified and interpreted the history of the same "pet rock"as in Pet Rock I. Rocks were collected on river levee next to science building. <u>Prompt</u>: Write the story of your pet rock. Identify the rock as accurately and precisely as you can, then tell as much as you can about how it formed. Look for as many clues in the rock as you can. Turn in your rock along with this assignment.

Table 1. Description of essays used in analysis.

Information transmitted by an instructor refracts through the prism (and perhaps through a combination of prisms) to produce a spectrum of student ideas about geology. The metaphor of the prism illustrates how many potential misconceptions are buried in the science we teach. Like the colors of the rainbow, these ideas don't emerge until instructional experiences are processed through students beliefs. The patterns of these misconceptions depend on the prisms each student has individually constructed, and the interactions between these prisms.

In cultural anthropology, "world view" is an individual's "culturally-dependent, generally subconscious, fundamental organization of mind" (Cobern, 1993, p.58). World view is a consequence of culture, religion, family influences, personality, psychological influences, and undoubtedly other factors. An individual's world view ultimately influences how the mind makes meaning of experience, whether in educational settings or in the broader world (Kelly, Carlsen and Cunningham, 1993; O'Laughlin, 1992).

Meaningful personal experience also plays a role in the creation of conceptual prisms. Students have experiences outside of school that shape their thinking about the world (Osborne and Freyberg, 1985). Virtually all students have some experience of the geologic world, be it hiking in the wilderness or observing the erosion of concrete in the inner city.

In an ideal educational setting, schooling would have at least as much influence in shaping student beliefs as world view and personal experience. Unfortunately, it appears that most schooling has little impact on student misconceptions and thus on the belief systems that generate them (Driver and Erickson, 1983). Instead, instruction is refracted through the conceptual prisms students have already constructed. The result can be a bewildering array of "funny ideas" about geology. Figure 1 shows only a single prism. In reality, students process school experiences through a variety of belief systems. The student misconceptions arising through the interactions of these prisms can be wildly unpredictable.

In this analysis, I suggest four possible conceptual prisms to explain the patterns of misconceptions expressed in student essays on rock formation. The prisms are hypothetical structures to explain the observed data - the misconceptions themselves.

Category	Explanation
Formation	Did the student explain the origin of the rock type, or the process of forming a pebble?
Lithification	What process did the student attribute lithification to?
Rock = ?	Did the student use the word “rock” to mean rock type, rock body, or clast?
Sense of time	How did the student describe the span of time required for rock formation?
Changing Earth	What kinds of changes in the Earth were cited by the student?
Accretion model	Did the student describe rocks as forming by any kind of accretion?
Erosional model	Did the student include erosional processes in rock formation?
Ign, Sed, Met?	What kind of rock did the student identify the pet rock to be? (Actual rock type of the rock was also recorded)
Formed where found?	Did the student describe the rock to have formed in the environment where it was collected?
Parent = product	In descriptions of sedimentary rock formation, did the student identify the source rock as the same rock type (e.g. Greywacke froms from the weathering of greywackey).
Human intervention	Were humans involved in the rock formation story?
Catastropic	Did rock formation require catastropic events?
Accuracy	Was the description of rock formation accurate, almost accurate, not accurate, or not addressed (e.g., only pebble formation was described).

Table 2. Coding categories.

Prism I: What is a rock? - This prism may be characterized less as a misconception than as a mismatch in communication between teacher and student. Geologists, like other scientists, adopt technical meanings for common words. To geologists, “rock” means a category (e.g., granite) or a large mass (e.g., Cathedral Peak Granite). When a geologist envisions a “rock”, he thinks on a large scale. To most people, a “rock” is a “stone” - what geologists call a “clast”. To students, a “rock” is something you hold in your hand. They may also use the geologists’ meaning when required, translating the question, “What rock is this” to mean “To what category of rock type does this sample belong?”. The problem arises when the geologist assumes that the student always uses the technical meaning. “How did this rock form?” can have very different meanings for the geologist and the student. The geologist translates the question as “To what category does this sample belong, and what is the process by which rock in that category forms?” Many students translate the question to mean, “How did this sample get to be a pebble?”

When we use words that have both a common meaning and a technical meaning, we must be very clear which meaning we intend. In common language, “minerals” are elements, “solids” are not hollow, and “crystal” is a kind of expensive glass. If we ignore these parallel meanings, students can build understandings around the wrong meaning with unpredictable results.

Among the ideas students expressed which can be attributed to this prism are:

Rocks are pebbles. Outcrops are large pebbles stuck in dirt.

Rocks form when pebbles break off outcrops and become rounded.

Rocks form by sediment sticking together in the bottom of rivers to make pebbles. These pebbles grow larger by accretion of more sediment.

Data supporting this prism include:

67% of students used “rock” only as a synonym for “clast”; the other 33% included references to “rock” as either a category (e.g., arkose) or a mass.

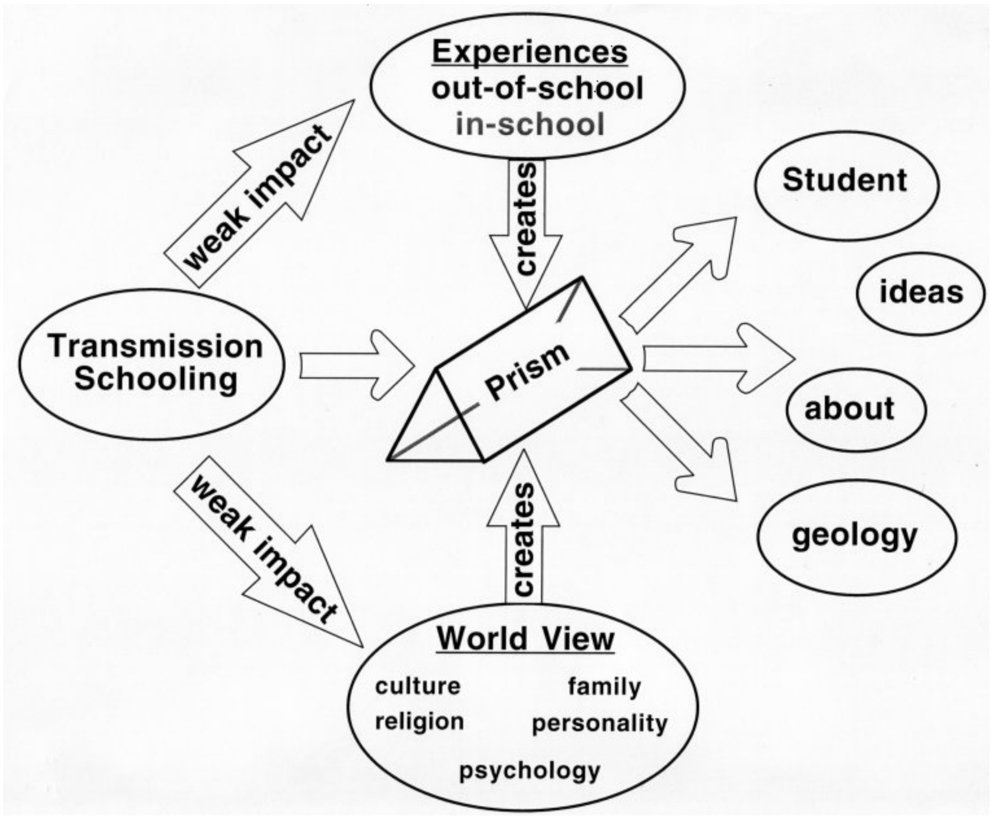

Figure 1. Conceptual prism model.

When asked to explain how a sandstone became a rock, 33% of students described the weathering and rounding of a pebble rather than the origin of the rock that comprises the pebble.

50% of students described some clast accretion process in rock formation, such as growing pebbles, globs of minerals that "melt together", etc.

Prism II: Scales of space and time - Humans view the world through human scales of space and time. All geology instructors recognize the difficulty in understanding geological scales of time. Thus we devote much attention to activities which illustrate the immensity of deep time (Zen, 2001). The difficulty we have is in recognizing the futility of those lessons. Students can quote the age of the earth, but they still cite surprisingly short time scales in describing rock formation.

Among the ideas students expressed which can be attributed to this prism are:

Sedimentary rocks form when puddles dry up and dirt "hardens up".

Humans play a role in rock formation, including weathering and transporting the sediment in an existing sedimentary rock.

Data supporting this prism include:

29% cited human intervention in weathering or transportation.

When describing how rocks form:

21% included no mention of time scales.
29% used general terms: "many years".
13% included specific mention of long time scales. (millions)
8% included specific mention of medium time scales. (thousands)
29% included specific mention of short time scales. (years or less)

Prism III: Stable Earth - Humans have a deeply felt belief in the stability of the Earth. This belief is manifested in the psychological trauma suffered by those who experience large earthquakes. The same belief also surfaces in students' inability to believe in the

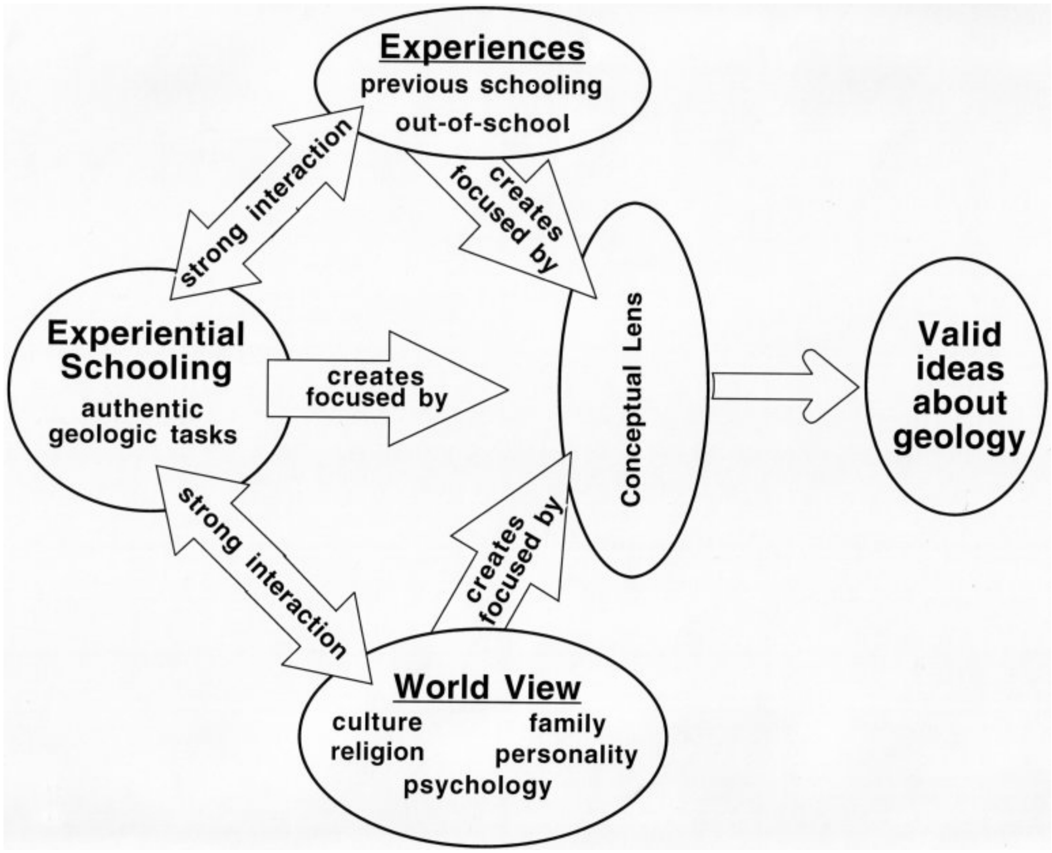

Figure 2. Instructional model for developing conceptual lenses in students.

transience of landscape. Students believe that rivers run where they have always run and that mountains stand forever. The flip side of this belief is that when change does happen, it must be catastrophic.

Among the ideas students expressed which can be attributed to this prism are:

Rocks are formed where they are found. A rock found in a river must be a sedimentary rock.

Rocks are formed through catastrophic events: weathering is caused by earthquakes or explosive volcanic activity.

Data supporting this prism include:

Only 38% included earth changes other than weathering in their rock explanations. Of those who mentioned other earth changes, 34% cited catastrophic explanations of rock formation.

33% described rocks forming where the rock was found.

Prism IV: Human Dominance - Students have difficulty imagining a world operating independently of human activity. When they envision the geological world, humans are in the foreground. Even when students have had instruction on geological rates and time scales, they still place humans in stories of rock formation. Studies of children's ideas reveal a human-centered view of phenomena as varied as pathways of light and the place of the earth in space (Osborne and Freyberg, 1985). Perhaps this anthrocentric view of the world persists in more subtle form into adulthood.

Among the ideas students expressed which can be attributed to this prism are:

Humans play a role in rock formation, including weathering and transporting the sediment in an existing sedimentary rock.

Data supporting this prism include:

In stories of rock formation, 29% of students cited human intervention in weathering or transportation.

EXAMPLES OF STUDENT RESPONSES

Most student essays exhibited a range of misconceptions supporting multiple prisms. A sampling of student work is provided here. Student writing is presented as is, complete with errors.

> "The rain and the strong waves push the pebble out of the ocean onto the seashore. Then the pebble somehow mix with the sand. Or the strong waves must have push the pebble to stuck with sand and become sandstone. The other way is when the river or lake dry up and the pebble and sand mixture to form a sandstone."

This student (who is not a native English speaker) describes an accretionary process, with lithification as a process of "dry up". She clearly thinks of "rocks" as "clasts". Her rock forming process has a very short time scale - as waves push sand to stick with the pebble, or as a lake dries up.

> "Long ago bits of Augite, Obsidian and various other minerals were weathered away by wind, rain and time. One day it rained and brought many of these little bits together in a puddle. In this puddle they mixed together with some clay materials which bound together and stuck them together. After the puddle had eventually evaporated all that was left of the little bits and clay was a big, hard rough lump of a mixture, and thus Rocky was born."

This accretion story includes an incredibly short time scale, with lithification as drying up on the surface of the earth. Again, a rock is formed as a "lump" - "rock as "clast". This story, like many, includes a fairly accurate depiction of weathering and erosion. Almost all the students in the study could tell accurate stories of erosion, and almost all of them recognized that weathering and erosion play an important role in rock formation. It was with the positive processes of rock formation that students stumbled.

> "My pet rock formed many years ago due to many minerals combining. As these minerals combined, they compacted to form a heavy mass - much larger than my pet rocks current size. … Many winters came and went along with winds and passing feet of people. One child once chose to pick this large mass up and toss it upon the other rocks situated along the water." [Wind, rain and hail smooth the rock.]

This student has people present through much of the generation of her rock. She describes a child breaking the rock, and wind, rain and hail smoothing the rock. She envisions this smoothing process as one that happens in human rather than geological time. Her rock formation process is vaguely accretionary - she doesn't provide a clear vision of how minerals "combine". She uses the term "mass" to describe the product of rock formation, but then describes a child lifting this "mass" - apparently a large clast.

DISCUSSION

While some students were able to produce rock stories that geologists would find valid, a startling number of students described rocks forming by processes no geologist would recognize. In this study, 83% of the students had already successfully completed a college-level course in earth science, yet still harbored some very ungeological ideas about rock formation. While individual student responses were not always consistent from essay to essay, there were some general patterns of student misconceptions. The four proposed prisms explain the range of misconceptions as interactions of belief systems with instruction. This study succeeded in identifying some previously unrecognized misconceptions. To investigate these misconceptions and others in more depth will require careful interviews of students, or development of specific assessment tools.

How can students who have passed a college-level earth science course retain such odd ideas about geology? The facile explanation is poor teaching. Yet in this group of students, the misconceptions were distributed across students who had studied geology at different institutions and with different instructors (including a very highly regarded instructor in my own department). How, then, to displace these students' misconceptions?

Constructivist educators use a range of instructional methods to confront misconceptions. These methods typically involve preassessments which reveal student thinking, explorations which challenge those misconceptions, student discussions that force students to defend their ideas, and collective model building so that students can learn from the thinking of other students (Driver, 1988; Roth, 1993; Wheatley, 1991).

Another approach may be to ask how geologists develop their ideas about the world. After all, we were all students once as well. How do geologists acquire the deep-seated beliefs that support scientifically valid ideas about rock formation?

Geologists learn when schooling, experience and world view interact to create a conceptual lens, rather than a prism. The conceptual lens is a belief system that focuses schooling experiences into a coherent way of thinking about the world. The scientific and geological experiences of the geologist help create a scientific world-view used to process new experiences and knowledge. The schooling experiences that most dramatically shape the belief systems of the budding geologist are experiential: field camp, problem-solving field trips, and the apprenticeship of graduate school. These experiences require an immersion in the thought patterns of geology, building core beliefs about the nature of the geological world.

How do we help students build beliefs that allow them to avoid misconceptions and develop deep understanding of geology? One possibility is to deliberately build constructivist instruction that mimics the geologist's model of conceptual understanding (Figure 2). This might mean providing students with opportunities to explore their existing beliefs about the Earth and previous experiences they have had that impact learning in earth science. Students can discuss or write about these experiences or beliefs in the context of explaining a new concept. Finally, students need schooling experiences which build a base for conceptual understanding, apprentice-like activities in which they can practice geological ways of thinking. Geologists develop deep understanding by solving geological problems, especially in the field. Students likewise need authentic geological tasks to practice thinking like a geologist. Traditional models of geological education often save this kind of task for late in the training of a geologist - for the senior-level field courses and graduate education. The model of the conceptual prism suggests that early authentic experiences can help students avoid misconceptions that may be difficult to overcome later in their education.

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Collaborative Partnerships that Link Geoscience Research and K-16 Education

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